

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

NBS REPORT

0201-20-2304

February, 1957

5138

REPORT

on

DESIGN OF CABLE-FED BUOY LIGHT

by

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Test 21A-8/55

for

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

1. Problem.

The problem discussed in this report is the design of a buoy light to be supplied by power through a submarine cable and used by aircraft pilots for guidance in landing and taking-off seaplanes. The request stated that the power supply would be a 20-ampere series circuit and that it was desirable to use the standard components now used for marker lights on such circuits as far as practicable. It also indicated a visibility throughout 360° azimuth is essential.

The problem may be resolved into three stages:

(I) The determination of the vertical spread required;

(II) The determination of the most efficient light source available for this use;

(III) The determination of the most efficient type of optical system for use with the selected light source.

Part I Vertical Spread

2. Wave Motion

The vertical spread required for the light is determined in part by the vertical angle of coverage required for use and in part by the angle of roll caused by the wave motion. The angle of roll was made the subject of our first investigation.

The rolling of a buoy may be caused in two ways. As the inclination of the wave surface to the horizontal varies with the passage of the wave, there is a tendency for the buoy to roll in such a way as to maintain the normal water line tangent to the wave surface. This is the obvious effect of waves, but rolling may also be caused by the flow of water within the wave itself. Each particle of water normally travels in an approximately closed orbit. If the water is deep enough this orbit will be nearly circular, but in shallow water it becomes an ellipse. The effect of the surface action could be counteracted if it were possible to extend the buoy laterally so that the difference in height of the water surface would be averaged over an appreciable area, or if the buoy were elongated vertically so as to minimize the surface action in comparison with that of the lower water. To overcome the effects of the orbital motion it would be desirable

to make the buoy shallow so that there would not be any large difference between the horizontal velocity of the water near the surface and that at the bottom of the buoy. The amplitude of the orbital motion decreases with increasing depth below the surface.

That it is not feasible to spread the buoy over sufficient surface area to accomplish any considerable stabilization is evident from the fact that good sized boats show considerable motion in water no rougher than that in which it is possible to land a seaplane. Increasing the horizontal cross section of the buoy also increases its menace as an obstruction. On the other hand, the depth to which it is feasible to extend the buoy is limited to less than 6 feet because some locations in which these buoys will be used do not have sufficient depth of water to accommodate a greater draught.

3. First Model Tests

The buoys presently used with batteries as a source of power have ring shaped floats the center openings of which are approximately one third the total diameter of the float and the radial cross section of the ring is oval rather than circular. Since these buoys roll considerably, it seemed desirable to investigate the possibility of other shapes in the hope that some might prove more stable although it was evident that the funds available would not support a systematic study of the problem. All that could be done was to build a few models and observe them under the action of waves in wave-tanks. Figures 1 and 2 show the cross sections of the models tried. These were all made on a scale 1/15 full size. The floats were made of foam plastic, except for one made of cork. The metal parts were brass, except when lead was used for ballast. The lantern was simulated in transparent plastic which has about the same weight per volume as a minimum weight lantern.

In figure 1, diagram A shows a model intended to simulate the present type of buoy except that its radial cross section was made circular instead of oval. Since a cable fed buoy will not require a battery tank, a brass disk has been used to sink the model to the mid-plane of the float. When this model was used to represent the present type of buoy, the vertical shaft was rigidly attached to the float but it was so designed that it could be supported by a ball and socket joint at the level of the float, which made it possible for the spindle to swing like a pendulum in any

vertical plane. For comparison with this model, a ball of cork was fitted with a counterweight on one side so that it would float with its center at the water level as shown in Diagram B. A pin was inserted in the top of the cork to assist in observing its rolling motion. A third model, diagram C, was designed as a compromise between the toric form and the spherical form.

These models were observed in a wave tank at this Bureau, but since this tank was not equipped for maintaining periodic waves, arrangements were made with the Beach Erosion Board for observing the models in one of their tanks. Waves of the different heights and wave-lengths shown in Table I were set up in this tank and each buoy model was floated on each type of wave long enough to establish a steady state.

Table I

Characteristics of Waves Used for Model Tests

Tank Waves				Simulated Waves		
Period T (Sec)	Length* L (Ft)	Height H (Ft)	H/L	Period T (Sec)	Length L (Ft)	Height H (Ft)
0.5	1.3	0.02	0.016	1.9	19.5	0.30
		0.08	0.062			1.2
		0.06	0.047			0.9
1.5	8.4	0.10	0.0087	5.8	126.	1.5
		0.40	0.035			6.0
		0.20	0.0174			3.0
2.5	15.2	0.12	0.0038	9.7	228.	1.8
		0.25	0.0078			3.8

H/L is a conventional index of wave steepness. The maximum tangent of the angle between the wave surface and a horizontal plane is of the order of 4 x the values listed above.

*

Calculated from formulae:

$$C = \sqrt{(GL/2\pi) \tanh(2\pi D/L)} \text{ and } C = L/T$$

$$\text{Hence } L = (GT^2/2\pi) \tanh(2\pi D/L)$$

C = Velocity of crest, ft/sec

G = Acceleration of gravity, ft/sec²

When the roll appeared steady, motion pictures were made at right angles to the direction of wave motion so as to record the amount of roll for each buoy. Subsequently these pictures were viewed in a projector several times by three engineers including a representative of the Bureau of Aeronautics. All were agreed that Model C gave the most satisfactory performance. The model representing the present type of buoys showed somewhat less lantern movement when it was tested with the spindle free than when it was tested with the spindle locked rigidly to the float. It was estimated that the roll was less than 15° from vertical in nearly all cases.

4. Later Models.

Models D and E, shown in Figure 2, were made to test the pendulum principle further. In model D the float being spherical acts as a ball and socket bearing for the annular ballast which is free to swing as a pendulum beneath the float. The ballast was designed as a ring to make it possible to bring the mooring cable as nearly straight down from the float as possible and for this same reason a weight was attached to the cable a short distance below the ring. This arrangement had the dual purpose of reducing the rolling torque from the mooring cable and lessening the danger that the cable would become fouled on the spindle, had one been used on the buoy. This model did not give promising results. The waves moved the float parallel to the surface while the ballast ring could only follow more slowly with a resultant rolling of the buoy, especially in short waves.

In general, models A, B, C, and D all remained fairly steady in long waves but rolled badly in short choppy waves. Model E was designed to give the lantern freedom to remain level notwithstanding the rolling of the buoy. In long waves, the result was the most encouraging obtained with any of the models; but with short choppy waves, the lantern rocked in the gimbals through as large an angle as did the lanterns of the other models.

Since none of the models showed much advantage over the present design, it was decided to abandon the experiments to reduce the rolling, and a conference was arranged with engineers of the American Gas Accumulator Division of the Elastic Stopnut Corporation to learn if their experience in designing marine buoys would enable them to suggest a better approach to the problem. No specific proposal for the buoy design resulted from this conference. The A.G.A. engineers believed

believed that any attempt to use a design which depended upon moving parts would lead to excessive maintenance problems. Giving the float a spherical shape at the waterline seemed to them a constructive principle but a detailed study would be necessary before a definite view of its value could be reached.

The stability of a floating buoy depends upon the relationship of three points in the buoy; the center of gravity, the center of buoyancy, and the metacenter. The metacenter is the point at which the line of the buoyant force* intersects the centerline of the buoy. In still water, all three points lie on the center line which is vertical when there is no wave action. The first effect of a wave is to move the center of buoyancy out from under the center of gravity towards the approaching wave. This gives rise to a couple causing the buoy to roll. The rolling, supplemented usually by the passing of the wave, moves the center of buoyancy to the other side of the center of gravity and the line of the buoyant force, which is now an approximately vertical line through the center of buoyancy, causes a reversed couple tending to right the buoy. The movement of the center of buoyancy within the buoy takes place along an arc centered approximately at the metacenter, and the direction of the buoyant force is always along the line connecting the center of buoyancy and the metacenter.

As long as any part of the float extends above the water line, there will be some change in the position of the center of buoyancy due to the surface effect of the waves. In general this effect becomes smaller in proportion as that volume of the float which is alternately submerged and above water is small in comparison with the volume of the float which remains continuously below the surface.

A completely stable buoy could be obtained by having the float completely immersed, but there is no simple way to do this other than to anchor it so that it will be below the surface of the water at low tide. If the lantern is supported from such a buoy, its height above the water surface will vary with the height of the tide, and this is very undesirable from the standpoint of indicating the location of the water surface. A further difficulty with this design arises from the necessity for providing day marking. If the float is entirely submerged it is then necessary to support a large day marker, as well as a lantern, above the surface. When there is much wind, this day marker will cause the float to roll over carrying the lantern with it.

*

Here used to include the pressures caused by particle motion as well as the usual static pressure.

Some buoys designed to contain meteorological radio transmitters have been made with long slender bodies which are held upright in the water by means of counterweights some little distance below the float chamber. This arrangement may result in considerable stability provided the length of the buoy and counterweight are large in comparison with the amplitude of the particle motion of the waves; otherwise, as observed above, the differential particle motion at different distances below the surface will introduce a rolling action independent of that caused by the fluctuation of the water line. As has been pointed out, it is not possible to use seadrome buoys of such deep draught.

It has been suggested that a buoy can be stabilized by extending a tube from its lower surface downward through some form of guide which is carried on a firmly grounded pile or tower. In the opinion of the engineers at the AGA Division, it would not be practicable to design a breakoff coupling which would prevent such a device from being a hazard to landing aircraft without having it so easily ruptured as to cause it to be broken frequently by strong wave action. It would also be subject to the maintenance difficulties characteristic of any device having moving parts which is used in the water without maintenance personnel in attendance.

The excessive rolling of the buoys in choppy waves suggests that some provision be made for damping the rolling. It was thought that the ring on the bottom of model C and the annular counterweight of model D would provide considerable damping. Unfortunately the provision of external damping increases the effect of differential particle velocity. This suggests that it might be worthwhile to investigate the possibility of some form of internal damping within the float. This of course would not be feasible if the float is made of foam plastic and is not hollow, a construction which makes it practically unsinkable. It might be possible if the float were made of relatively thin rubber which was held in shape by internal air pressure. Metal buoys offer greater collision hazard.

At the conference with the AGA engineers, they expressed the view that 15° vertical spread would be adequate to provide for the rolling and angle of coverage throughout which buoys must be seen in service. This estimate appears too small, but in view of the fact that the model experiments have not resulted in any reliable quantitative information no definite recommendation for vertical spread can be made.

For the same reason it is suggested that the design for a float be referred to one or two companies having experience in designing buoy floats since it does not appear feasible to obtain any new engineering data on the performance of buoy floats without the expenditure of more funds than are likely to be available.

Part II - Light Source

5. Relative Efficiency of Mercury and Incandescent Lamps.

Since the seadrome marker lights are required to give a green light, it appeared possible that a mercury lamp might provide a more efficient source than an incandescent lamp. An investigation of the relative efficiency of the mercury lamp and the incandescent lamp, both used with appropriate filters, to give signal lights within the limits of aviation green was reported in NBS report 4449, "Analysis of Mercury Lamps and Filter Combinations for use as Aviation-Green Lights". Table IV of that report indicates that it is possible to obtain an aviation green light with a filter having a luminous transmittance of 0.66 from a B-H6 mercury lamp. With an H-250-A5 mercury lamp, aviation green can be obtained with a filter having a luminous transmittance of 0.48. In view of the facts that the mercury lamp produces flux more efficiently than the incandescent lamp, and that these transmittance values are much higher than those of any filters which are satisfactory for use with incandescent lamps, it appeared that the use of the mercury lamp might be advantageous.

There is, however, another consideration which must be taken into account. The visibility of a light in any direction depends not upon the total luminous flux being radiated by that light, but upon the candlepower in the direction of the observer. With a compact, high-luminance light source it is feasible to use an optical system which considerably increases the light flux in the useful directions. As the size of the light source becomes larger, it is necessary to increase the size of the optical system proportionately to obtain a corresponding degree of candlepower magnification. With the light source of a mercury lamp, the optical system required becomes impractically large. Table II compares the incandescent and mercury light sources taking this into account.

Table II

Comparison of Mercury and Incandescent
Lamps as Sources for Seadrome Buoy Lights

Lamp type	Mercury		Incandescent
	B-H6	H-250 A-5	Beacon 30V
Watts	1000	250	500
Total lumens	65000	8900	10000
Lumens per watt (lpw)	65	35.6	20.0
Source length (inches)	1.0	2.375	0.39
Lpw/in.	65.0	15.0	51.
Filter or combination	A	B	7356C
Transmittance for pale lim.	0.66	0.48	.250
Green lpw	43.	17.1	5.0
<u>Green lpw</u> in	43.	7.2	12.8

Since the seadrome lights are required to be seen throughout 360° of azimuth, it is only possible to concentrate the flux with respect to the vertical angle. For this reason the horizontal diameter of the light source is of little importance since the apparent width of the effective light source produced by the optical system is the same as that of the light source itself. Thus if we double the horizontal diameter of the light source and diminish to one-half its luminance, we still have the same candlepower available in the direction of the observer and this is equally true whether we are considering the bare light source or the same light source used with an optical system which concentrates the flux with respect to the vertical angle only. In Table II therefore, we have listed the several factors which determine the luminous flux per vertical inch of light source per watt of power required and shown their effect on the signal. The final line of the table gives a comparison of the effectiveness of incandescent-lamp and mercury-lamp sources.

Table II shows an advantage for the B-H6 mercury lamp, but the B-H6 is the high-pressure lamp which cannot be operated without special provision for cooling and this would very considerably complicate the design of a buoy. For this reason, it is our conclusion that it would be wiser to continue the use of incandescent filament lamps in seadrome lights, unless it should turn out that the vertical spread required is so great as to make the effect of an optical system relatively minor.

Part III - Optical System

6. Lenses and Reflectors

The conventional optical system for a light of 360° azimuth is a cylindrical lens with the light source at its focal center. An alternate system, which has been used in a few marine lights, consists of a reflector having an upper and lower cone of parabolic curvature. The optical surfaces of the reflectors are those generated by two parabolic arcs rotated about a vertical axis through their common focus. The axis of the generating parabola is directed at the vertical angle at which the maximum intensity is desired. Unless the light source is very small the dimensions required to obtain much magnification of candlepower from this device are so large as to make it an impracticable device for use on a buoy.

A third type of optical system which should be considered consists of a conventional parabolic reflector with the light source at its focus and its axis directed vertically, in combination with an inverted conical reflector the axis of which is collinear with that of the parabolic reflector. In this

device the parabolic reflector produces a vertical beam which is redirected by the conical reflector to form an approximately horizontal fan of light, 360° in azimuth. This type of optical system was discussed with the AGA engineers in comparison with the conventional cylindrical lens and it was their opinion that it offered considerable promise for the present application.

7. Filters.

If in accordance with the discussion in Part II an incandescent filament source is selected, the combination of an incandescent filament and a parabolic reflector is available in the PAR type lamps. This would appear to be a very promising type of lamp for use in cable-fed seadrome buoys. With such a lamp it will be necessary to use a filter which will transmit only green light of an acceptable chromaticity. This could be made in the form of a cylinder surrounding the inverted conical reflector. This arrangement provides the maximum possible cooling for the filter but the temperature would still be too high for a plastic filter. It was the opinion of the AGA engineers that, if the protecting cylinder of the unit is to be plastic, the lamp should not be larger than 200 watts. It was also their opinion that the green filter must be inserted separately from the plastic as it will absorb a great deal of heat and they have had difficulty in getting even a clear plastic cover to withstand the temperature incident to the use of a 200-watt lamp.

There is available a green plastic** which can be used for both a protecting cover and a filter provided some means of eliminating a large part of the unwanted radiation can be inserted between the light source and the filtering cover.

Interference filters are now being made by several companies which offer a possible means of doing this. An interference filter can be made which will reflect selectively in the green portion of the spectrum and transmit most of the red and infrared, blue and ultraviolet radiation. If it is practicable to make interference-filter reflectors in conical form, of light-weight, and at permissible expense, it could be used both as a reflector to turn the vertical beam into a horizontal fan and as a heat eliminator. Such a reflector with a green plastic cover would probably produce the lightest weight optical system. It appears probable that such a reflector could transmit 80% of the radiant energy into a black top from which it could be invisibly radiated. This should make it possible to increase the lamp wattage to 500 watts and still use a green plastic cover. If such an interference filter is not practical, it may be just as economical both in weight and in costs to use an aluminum conical reflector with a green glass cylindrical cover.

** See N.B.S. Report 3476

BUOY MODELS

VERTICAL SECTIONS

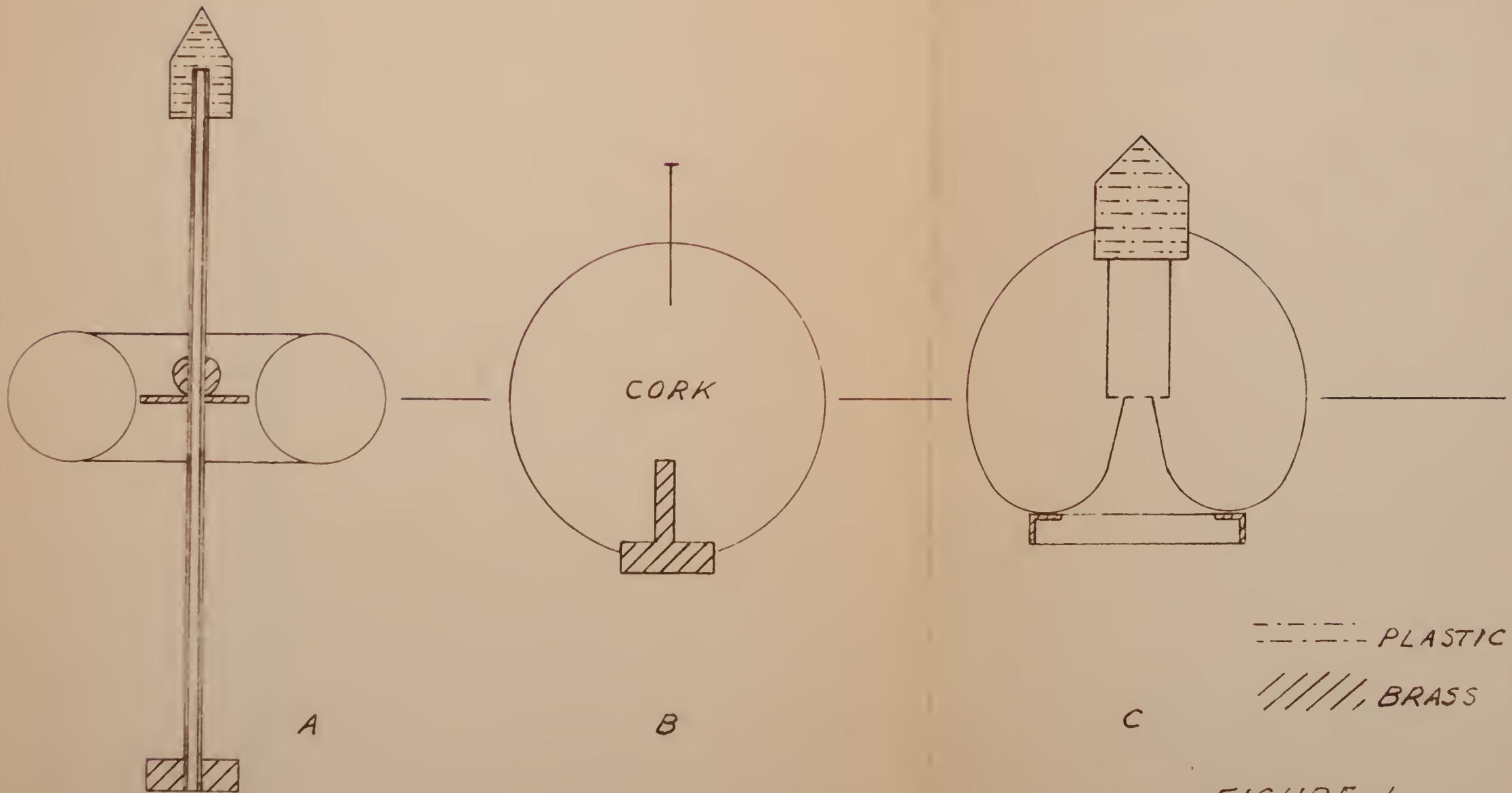


FIGURE 1

BUOY MODELS

VERTICAL SECTIONS

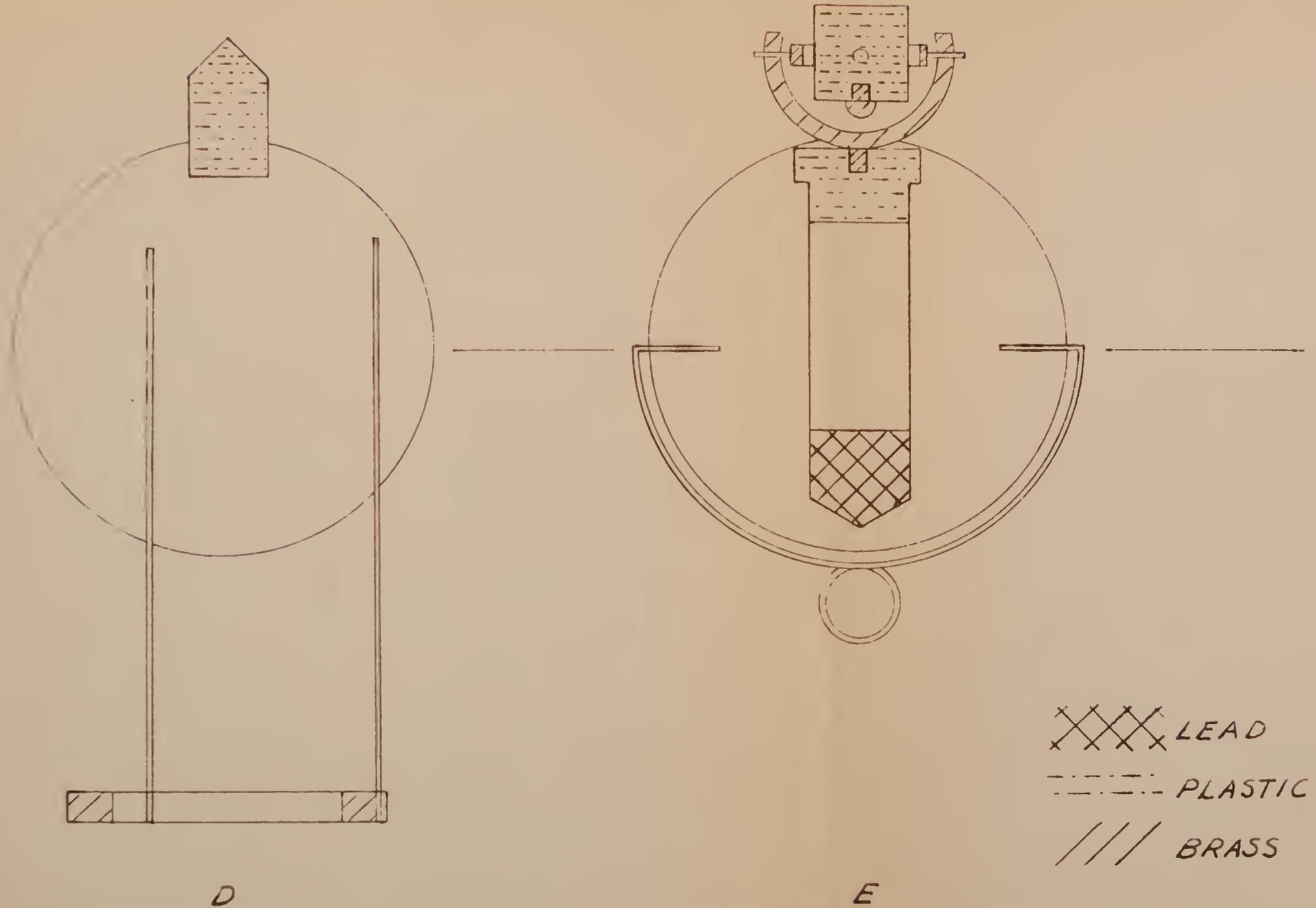


FIGURE 2

